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FRANKFORD ARSENAL

DETERMINATION OF TEMPERATURE-TIME LIMITS FOR SAFE OPERATION OF 20 mm AMMUNITION

by

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ABSTRACT

The temperature-time limits permitting safe operation of 20 mm M55 ammunition, as defined by a maximum chamber pressure of 70,000 psi or maximum action time of 4.0 msec, were determined for the following conditions: (1) exposure and firing at elevated temperature; (2) exposure at elevated temperature and firing at 70° and -65° F; (3) exposure and firing at -65° F. A maximum exposure time of twelve hours was employed.

The large temperature coefficient of pressure of the ammunition was the factor limiting its high temperature use. Firings at 185° F yielded chamber pressures above 70,000 psi. At this temperature the peak pressure did not vary significantly with exposure time up to twelve hours. Ammunition exposed to temperatures in the range of 200° F for twelve hours and fired at 70° F yielded pressures above 70,000 psi. Similar pressures were obtained with ammunition heated at higher temperatures for shorter periods of time. Nomograph-like tables were prepared, defining the exposure temperature-time conditions which resulted in pressures exceeding the safe operating limit. Exposure and firing at -65° F had no significant effect upon ballistic performance beyond that normally due to temperature coefficient of ballistics.

Ammunition assembled with two WC 870 propellant lots was evaluated in this program. In general, the two lots yielded similar performance. The large pressure increases obtained with ammunition subjected to high temperature-time exposure conditions and fired at 70° and -65° F are believed attributable to migration of the deterrent coating of the WC 870 propellant. The slight changes in chemical composition of the propellant induced by these exposure conditions could not account for the large pressure increases. Exposure of ammunition to temperatures above 200° F caused significant agglomeration of the propellant.

INTRODUCTION

The extreme temperatures to which 20 mm aircraft ammunition may be subjected are such that the ballistic performance of the ammunition might be significantly impaired. The advent of supersonic aircraft introduced problems due to aerodynamic heating, including the effect of high temperature upon ammunition carried in these aircraft. It has been estimated that temperatures equal to or greater than 260° F will be developed in the ammunition boxes or gun compartments of these high-speed aircraft. Firings previously conducted with standard 20 mm aircraft ammunition in the range 165° to 255° F resulted in extremely high chamber pressures under certain test conditions. Significant changes in velocity, propellant ignition time, and action time (interval between primer initiation and muzzle exit of projectile) were also obtained, but these were small and not sufficient to impair gun functioning characteristics.(1)

While refrigeration could be used to maintain ammunition boxes and gun compartments at a safe temperature during the high speed portions of a mission, the added weight and space of a refrigerating system are not desirable. High temperatures might also be induced in ammunition directly exposed to the high solar radiation and temperatures encountered in desert regions. However, both these conditions, which promote ammunition temperatures substantially in excess of ambient, would not involve extended exposure periods but, rather, exposures measured in terms of hours. Long term desert storage tests at Yuma Test Station, Arizona, involving 7.62 mm ammunition stored in normal packaging showed that the ammunition can safely withstand extended desert exposure when stored in the conventional manner. Both the cardboard carton and wooden boxes serve to insulate the ammunition from the high ambient temperatures and solar radiation.(2)

Aircraft ammunition may also be subjected to extremely low temperatures. Such conditions may occur in arctic regions as well as in the gun compartments and ammunition boxes of aircraft cruising at high altitudes at subsonic speeds.

These widely divergent conditions emphasize the importance of the requirement that aircraft ammunition perform satisfactorily over a wide temperature range. While current operational requirements call for satisfactory performance from -65° to 160° F the effect of aerodynamic heating coupled with the high temperature sensitivity of the standard ammunition indicates a need for satisfactory performance at temperatures in excess of 160° F. In addition, the results obtained in reference 1 indicated a need for delineation of the temperature-time conditions under which standard 20 mm ammunition could be safely exposed and fired.

The ballistic performance of ammunition at these extreme temperatures may be affected by several factors:

1. The effect of temperature upon ballistics, where the exposure time is the minimum required to insure equilibrium cartridge temperature.

2. The effect of extended exposure at an elevated temperature upon ballistics coupled with

   a. Firing at the exposure temperature;

   b. Firing at a different temperature.

3. The effect of temperature upon the probability of spontaneous ignition of the various explosive constituents of the ammunition.

These conditions and their effects are described in detail in reference 1.

APPROACH

The investigations described herein were directed toward determination of the temperature-time limits for safe operation of service 20 mm aircraft ammunition. Two major parameters were established as defining these limits, viz, mean pressures (as determined by copper crusher gages) not to exceed 70,000 psi and individual action times not to exceed 4.0 milliseconds. It was also desired to determine what conditions would cause the mean projectile velocity to differ from the required 3380 fps level by more than 200 fps. This criterion, however, was not used in defining the safe operating limits. Exposure times were limited to twelve hours since this was believed to represent a realistic maximum period for which ammunition would be exposed to extreme temperature conditions.[3] The effect of the following test conditions upon the ballistics of 20 mm ammunition was determined.

(1) Exposure and firing at elevated temperature.

(2) Exposure and firing at -65° F.

(3) Exposure at elevated temperature and firing at 70° and -65° F.

The firing program was conducted with standard components assembled with WC 870 ball propellant and the M52A3B1 primer, which are the constituents of the ammunition now in service. Two WC 870 propellant lots, AL 42446 and AL 42678, were evaluated to determine whether cartridges containing different propellant lots exhibited similar safe operating limits. Ammunition containing AL 42446 propellant was hand-loaded at Frankford Arsenal, while that containing AL 42678 propellant was assembled at Lake City Arsenal (ammunition lot LC-L-16-9). Description sheets of the two propellants are given in the Appendix. A complete description of the cartridges loaded with each propellant is given in Table I.

TABLE I. Description of Ammunition Used in Ballistic Tests

Cartridge: 20 mm M55 Primer: M52A3B1
Case: 20 mm M103 (brass) Projectile: 20 mm FA T283E1

Propellant	Charge (gr)	Velocity at 78 ft (fps)	Pressure (psi)
WC 870, AL 42446	600[a]	3397	51,500
	615[b]	3384	47,000
WC 870, AL 42678	605	3357	50,100

[a]Used in first and second test conditions.
[b]Used in third test condition.

Ballistic specifications for this cartridge call for a velocity of 3380 ± 50 fps at 78 feet and a maximum mean pressure of 58,000 psi (copper). The following ballistic parameters were determined: projectile velocity at 78 feet, chamber pressure (copper), and action time. All pressure and velocity values were corrected through use of reference ammunition.

Preliminary high temperature firings were conducted using the test weapon as the heating medium to obviate the need for handling ammunition at very high temperatures. However, when it was determined that the safe operating limit of 70,000 psi was exceeded at firing temperatures below 200° F, it was decided that the required test temperatures were sufficiently low so that safety considerations did not require using the test weapon as a heating medium. Instead, the ammunition was heated for the desired temperature-time schedule in an oven adjacent to the test weapon; the chamber of the weapon was maintained at the intended firing temperature. Since several cartridges could be simultaneously conditioned in the oven, in contrast with the heated weapon method which permitted conditioning only one cartridge at a time, a considerable increase in the rate of firing resulted. The interval between removal of the round from the conditioning oven and insertion in the chamber was no more than 20 seconds. The round remained in the chamber for no more than 30 seconds prior to firing.

Firings at 70° and -65° F were conducted in a standard test barrel. Ammunition subjected to elevated temperature exposure and then fired at normal or low temperature was rapidly cooled by blowing air at room temperature through the oven after completion of the exposure temperature-time schedule. The cartridges were then conditioned at 70° or -65° F for at least two hours prior to firing.

RESULTS

Exposure and Firing at Elevated Temperature

Firings were conducted to determine the elevated temperature-time conditions (coupled with firing at the exposure temperature) which would result in the mean pressure or action time exceeding safe operating limits of 70,000 psi or 4.0 msec., respectively.

Previous experience[1] suggested that the relatively high temperature coefficient of pressure of the standard 20 mm M55 cartridge would result in the pressure limit being exceeded at temperatures in the neighborhood of 200° F. Consequently, the first experimental firings with ammunition assembled with WC 870 AL 42446 propellant were conducted at this temperature.

The test barrel, fitted with a heated chamber, was initially used in these firings to obviate the need for handling cartridges conditioned at high temperatures. Ballistic tests were conducted at exposure and firing temperatures ranging from 185° to 200° F, with exposure times ranging from zero to twelve hours. (The time required to heat the propellant to the desired equilibrium temperature, approximately twenty minutes, is not included in the indicated exposure time). All extended exposure performance was determined as an average of three firings; zero time exposure values were based on an average of five.

For a given temperature in the above range, the pressure did not vary significantly with an increase in exposure time to a maximum of twelve hours. However, pressures in excess of the safe operating limit of 70,000 psi were attained even at 185° F. These high pressures were indicative of the large temperature coefficient of pressure of the test ammunition.

In view of the relatively low temperature at which the safe operating pressure limit was exceeded, it was decided that safety reasons no longer necessitated using the gun chamber, with its severe limitation on the rate of firing, as the heating medium. An oven (located near the test action) was subsequently used to condition ammunition for the required time-temperature schedule. The gun chamber temperature was maintained at that of the ammunition.

Use of the oven as the heating medium permitted elimination of a source of error in pressure measurement. When the gun was used as the heat source, the copper crusher cylinder, located deep in the chamber wall, was subjected to the exposure temperature for the entire heating period, since it was not possible to effectively cool it. The effect of the extended high temperature upon both the compressibility and surface area of the cylinder should result in slightly higher pressure readings. This problem was not encountered in firings where the oven was used as the heat source since the copper cylinders were inserted in the chamber wall immediately prior to firing.

The high temperature firings with test cartridges assembled with WC 870 AL 42446 propellant were therefore repeated. In addition, similar tests were conducted with ammunition (Lot LC-L-16-9) assembled with a different lot of the standard WC 870 ball propellant, AL 42678. The results obtained in these tests are presented in Tables II and III.

The indicated exposure times in all tests involving oven heating do not include the time (approximately 30 minutes) required to heat the cartridge to the desired exposure temperature. All extended exposure values represent averages of three firings; zero exposure time values are based on an average of five firings.

Some comments regarding these results follow.

Pressure. Cartridges loaded with either propellant yielded pressures exceeding the safe operating limit of 70,000 psi at approximately 180° to 185° F. At these temperatures the pressure did not vary significantly with an increase in exposure period. The safe operating limit was therefore defined by a maximum temperature and was independent of exposure times up to 12 hours. Thus, the limiting factor was the undesirably large temperature coefficient of pressure of the standard ammunition. In general, for a given temperature, the pressures obtained in the above firings with AL 42446 propellant (where an oven was used as the heating medium and the copper cylinders were inserted immediately prior to firing) were approximately 2000 psi lower than those obtained when the chamber was used as the heat source and the copper cylinder subjected to high temperature for the entire exposure period. The data obtained under the latter condition are not presented since, as previously mentioned, it is believed the measured pressures are high due to the increase in compressibility and surface area of those copper cylinders subjected to high temperature exposure.

Velocity. All measured velocities were within the desired range of 3380 ± 200 fps. For a given propellant and exposure temperature, the projectile velocity was not significantly affected by an increase in exposure time.

Action Time. All action times were well within the safe operating limit of 4.0 msec. For a given exposure temperature, action times decreased with an increase in exposure time. Since

TABLE II. Effect of Exposure and Firing at Elevated Temperature (WC 870 AL 42446 Propellant, M52A3B1 Primer)

Exposure and Firing Temperature (°F)	Exposure Time (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)
190	0	73,600	3516	2.46
	EV[a]	3,300	11	0.07
	SD[b]	1,200	5	0.03
	2	72,900	3504	2.45
	EV	4,400	24	0.06
	SD	1,900	10	0.03
	4	73,500	3510	2.45
	EV	1,400	16	0.04
	SD	700	7	0.02
	8	71,100	3507	2.42
	EV	600	1	0.02
	SD	200	1	0.01
	12	70,000	3514	2.38
	EV	2,000	16	0.08
	SD	800	7	0.03
185	0	72,200	3512	2.46
	EV	3,300	16	0.01
	SD	1,400	7	0.01
	2	71,800	3497	2.46
	EV	2,200	13	0.01
	SD	1,000	6	0.01
	4	72,700	3527	2.45
	EV	2,200	9	0.00
	SD	1,000	4	0.00
	8	73,900	3522	2.43
	EV	1,600	6	0.02
	SD	700	3	0.01
	12	73,700	3526	2.40
	EV	4,400	22	0.03
	SD	1,900	9	0.01
180	0	72,100	3505	2.49
	EV	2,400	10	0.07
	SD	1,000	4	0.02
	2	71,000	3490	2.50
	EV	5,200	22	0.08
	SD	2,100	9	0.03
	4	71,500	3513	2.44
	EV	1,100	3	0.04
	SD	500	1	0.02
	8	72,800	3510	2.45
	EV	1,600	9	0.03
	SD	800	4	0.01
	12	69,600	3514	2.44
	EV	2,500	17	0.05
	SD	1,100	7	0.02

[a]Extreme variation
[b]Standard deviation
NOTE: Ballistic results for zero and extended exposure times are based on averages of five and three firings, respectively.

TABLE III. Effect of Exposure and Firing at Elevated Temperature (WC 870 AL 42678 Propellant - M52A3B1 Primer)

Exposure and Firing Temperature (° F)	Exposure Time (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)
190	0	74,000	3483	2.47
	EV	2,800	23	0.05
	SD	1,200	8	0.02
	2	73,300	3480	2.47
	EV	3,300	7	0.07
	SD	1,600	3	0.03
	4	71,600	3465	2.48
	EV	1,600	20	0.05
	SD	800	9	0.02
	8	72,700	3485	2.40
	EV	3,800	23	0.10
	SD	1,600	10	0.04
	12	74,000	3502	2.37
	EV	2,100	41	0.06
	SD	1,000	18	0.03
185	0	70,100	3475	2.48
	EV	6,800	41	0.04
	SD	2,300	14	0.02
	2	72,600	3476	2.45
	EV	4,400	21	0.01
	SD	2,100	9	0.01
	4	70,900	3480	2.45
	EV	4,300	33	0.03
	SD	1,800	10	0.01
	8	72,900	3500	2.41
	EV	600	10	0.01
	SD	300	4	0.01
	12	74,600	3519	2.38
	EV	3,600	39	0.02
	SD	1,500	16	0.01

NOTE: Ballistic results for zero and extended exposure times are based on averages of five and three firings, respectively.

there was no significant effect of exposure time upon projectile velocity, the reduced action time is probably related to a reduction in the propellant ignition time.

Thus, the results may be summarized as follows. At temperatures in the order of 180° to 185° F, M55 cartridges assembled with either WC 870 propellant lot yielded pressures equal to or greater than the 70,000 psi safe operating limit. Since pressures were independent of exposure time (maximum of 12 hours), the factor determining the safe operating limit is the undesirably large temperature coefficient of pressure of the standard ammunition. Action times in all firings were well within the maximum permissible limit of 4.0 msec. Projectile velocities were all within the desired range of 3380 ± 200 fps.

Exposure and Firing at -65° F

To determine whether exposure at low temperature (-65° F) coupled with firing at the exposure temperature had any significant effect upon the ballistics of 20 mm M55 ammunition, cartridges were exposed to -65° F for two or twelve hours and then fired in the test action which was at room temperature. (The time required for the propellant to attain the -65° F equilibrium temperature, approximately 30 minutes, is included in the indicated exposure period.) The results of these tests are presented in Table IV. All values represent averages of five firings.

There was no difference of consequence between the ballistic performance of cartridges stored for two or twelve hours at -65° F indicating that exposure at -65° F for as long as twelve hours coupled with firing at that temperature should not have any detrimental effect beyond that normally due to temperature coefficient of ballistics. The maximum individual action time in these firings was 2.86 msec, which is substantially below the safe operating limit of 4.0 msec. Chamber pressures were in the range 40,000 to 50,000 psi, considerably less than the specified 70,000 psi maximum. Velocities at -65° F were substantially lower than those obtained at 70° F, indicating the large temperature coefficient of velocity of the test cartridges. While the projectile velocities were within the desired range of 3380 ± 200 fps, several of the tests yielded mean velocities approaching the minimum.

TABLE IV. Effect of Exposure and Firing at -65° F
(WC 870 Propellant, M52A3B1 Primer)

Propellant Lot	Exposure Time at -65° F (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)
42446	2[a]	45,300	3255	2.76
	EV	3,300	29	0.03
	SD	1,100	10	0.01
	12[a]	43,400	3240	2.81
	EV	4,900	75	0.14
	SD	1,600	25	0.05
	2[b]	43,300	3201	2.68
	EV	3,700	88	0.18
	SD	1,500	31	0.07
	12[b]	42,500	3194	2.79
	EV	4,300	41	0.08
	SD	1,500	14	0.03
42678	2	44,200	3218	2.77
	EV	5,800	101	0.17
	SD	2,400	33	0.06
	12	44,300	3222	2.78
	EV	6,300	102	0.09
	SD	2,200	36	0.03

[a] Original Test
[b] Repeat Test
NOTE: Ballistic results represent averages of five firings.

Exposure at Elevated Temperature and Firing at 70° and -65° F

Firings were conducted with ammunition assembled with WC 870 AL 42678 and WC 870 AL 42446 propellant lots to determine the elevated temperature-time exposures, coupled with firing at 70° and -65° F, which would result in the pressure or action time exceeding the safe operating limits of 70,000 psi and 4.0 msec, respectively. Previous firings indicated that pressure, rather than action time, would be the critical parameter. Consequently, the temperature-time exposures selected were such as to yield pressures in the region of 70,000 psi, permitting delineation of the safe operating conditions. Ammunition was heated in an oven for predetermined temperature-time conditions (maximum of 12 hours) and then rapidly cooled to room temperature. The cartridges were then conditioned at 70° and -65° F and fired in a test action which was at room temperature. Unheated cartridges were also fired at 70° and -65° F for comparison purposes. All values reported represent averages of five firings. The data are given in tables which follow, both in tabular and nomograph form. In the former, the data are presented in the order in which the tests were conducted. In the latter, the mean performance values (pressure, action time, and velocity) are presented as a function of the exposure time and temperature.

The results obtained with ammunition assembled with WC 870 AL 42678 propellant and the M52A3B1 primer are presented in Tables V, VI, VII, and VIII.

Following are some comments regarding these results.

<u>Pressure</u> - For the ammunition fired at 70° F, the exposure temperature-time conditions which yielded pressures below the safe operating limit of 70,000 psi are located below the line in Table VI. Ammunition exposed to conditions located above the line yielded pressures above 70,000 psi. While the ammunition can withstand 12 hours' exposure at 195° F without exceeding the pressure limit, the exposure has a serious effect upon the ammunition, as indicated by the fact that the pressure was 13,600 psi greater than that obtained with standard ammunition. For similar exposure conditions, firings at -65° F yielded pressures approximately 9000 psi less than those obtained at 70° F.

TABLE V. Effect of Exposure at Elevated Temperature and Firing at 70° or -65° F (WC 870 AL 42678 Propellant-M52A3B1 Primer)

Firing Temperature: 70° F					Firing Temperature: -65° F				
Exposure					Exposure				
Temp (° F)	Time (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)	Temp (° F)	Time (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)
70		50,100	3357	2.56	-65		44,200	3218	2.77
	EV	3,900	38	0.07		EV	5,800	101	0.17
	SD	1,300	14	0.03		SD	2,400	33	0.06
195	12	63,700	3371	2.44	195	12	58,100	3266	2.58
	EV	4,500	38	0.06		EV	3,200	97	0.07
	SD	1,700	14	0.02		SD	1,100	35	0.03
200	12	72,200	3409	2.38	200	12	61,100	3235	2.58
	EV	1,500	38	0.07		EV	4,800	19	0.03
	SD	500	14	0.03		SD	1,700	6	0.01
200	10	73,300	3424	2.37	200	10	62,300	3259	2.58
	EV	4,000	27	0.02		EV	2,700	37	0.18
	SD	1,300	9	0.01		SD	900	13	0.06
205	8	68,400	3399	2.39	205	8	59,100	3237	2.56
	EV	2,600	30	0.02		EV	12,500	88	0.08
	SD	900	11	0.01		SD	4,100	30	0.03
205	9	68,400	3417	2.38	205	9	62,800	3256	2.57
	EV	7,000	50	0.06		EV	7,300	162	0.06
	SD	2,300	18	0.02		SD	2,800	57	0.03
210	8	75,100	3415	2.35	210	8	63,000	3257	2.55
	EV	2,300	28	0.03		EV	4,200	20	0.05
	SD	800	9	0.01		SD	1,800	8	0.02
210	6	69,900	3390	2.39	210	6	61,200	3253	2.56
	EV	3,000	22	0.04		EV	2,200	41	0.07
	SD	1,100	8	0.02		SD	800	14	0.02
210	4	66,200	3384	2.41	210	4	57,900	3220	2.63
	EV	1,600	21	0.03		EV	7,400	82	0.09
	SD	600	8	0.01		SD	3,000	34	0.03
215	4	71,400	3390	2.40	215	4	62,300	3255	2.55
	EV	4,100	42	0.08		EV	2,500	47	0.07
	SD	1,500	15	0.03		SD	900	16	0.03
215	3	68,700	3416	2.40	215	3	58,700	3246	2.59
	EV	2,700	31	0.03		EV	5,200	41	0.05
	SD	900	13	0.01		SD	1,800	13	0.02
220	3	69,500	3404	2.40	220	3	60,100	3242	2.59
	EV	2,900	48	0.11		EV	3,500	47	0.06
	SD	1,200	17	0.04		SD	1,400	16	0.02
220	2	63,000	3380	2.43	220	2	57,700	3248	2.62
	EV	4,200	20	0.05		EV	6,500	58	0.07
	SD	1,500	7	0.02		SD	2,300	21	0.02
225	2	66,200	3398	2.41	225	2	57,300	3247	2.58
	EV	2,500	28	0.06		EV	2,100	45	0.07
	SD	900	10	0.02		SD	700	15	0.02
230	2	69,600	3398	2.40	230	2	60,200	3256	2.58
	EV	3,000	32	0.04		EV	1,400	32	0.06
	SD	1,200	11	0.02		SD	600	11	0.02
225	1	62,900	3396	2.42	225	1	57,300	3259	2.61
	EV	3,500	27	0.01		EV	8,400	70	0.06
	SD	1,200	9	0.01		SD	3,200	27	0.02
230	1	70,200	3402	2.40	230	1	61,200	3257	2.56
	EV	4,500	21	0.08		EV	2,700	30	0.09
	SD	1,400	7	0.03		SD	1,100	11	0.03

Ballistic results represent averages of five firings.

TABLE VI. Pressures Obtained under Various High Temperature-Time Exposures (WC 870 AL 42678 Propellant-M52A3B1 Primer)

Firing Temperature: 70° F

Exposure Temp (° F)	Pressure (psi) after Exposure Time (hr) of 1	2	3	4	5	6	7	8	9	10	11	12
235												
230	70,200	69,600										
225	62,900	66,200										
220		63,000	69,500									
215			68,700	71,400								
210				66,200		69,900		75,100				
205								68,400	68,400			
200										73,300		72,200
195												63,700

Pressure at 70° F, 50,100 psi (unheated cartridges).
Temperature-Time conditions below line represent exposures where pressures are equal to or below the safe operating limit.

Firing Temperature: -65° F

Exposure Temp (° F)	Pressure (psi) after Exposure Time (hr) of 1	2	3	4	5	6	7	8	9	10	11	12
235												
230	61,200	60,200										
225	57,300	57,300										
220		57,700	60,100									
215			58,700	62,300								
210				57,900		61,200		63,000				
205								59,100	62,800			
200										62,300		61,100
195												58,100

Pressure at -65° F, 44,200 psi (unheated cartridges).

TABLE VII. Action Times Obtained Under Various High Temperature-Time Exposures (WC 870 AL 42678 Propellant-M52A3B1 Primer)

Exposure Temp (° F)	Action Time (msec) after Exposure Time (hr) of											
	1	2	3	4	5	6	7	8	9	10	11	12
						Firing Temperature: 70° F						
235												
230	2.40	2.40										
225	2.42	2.41										
220		2.43	2.40									
215			2.40	2.40								
210				2.41		2.39		2.35				
205								2.39	2.38			
200										2.37		2.38
195												2.44

Action time at 70° F, 2.56 msec (unheated cartridges).

Exposure Temp (° F)	1	2	3	4	5	6	7	8	9	10	11	12
						Firing Temperature: -65° F						
235												
230	2.56	2.58										
225	2.61	2.58										
220		2.62	2.59									
215			2.59	2.55								
210				2.63		2.56		2.55				
205								2.56	2.57			
200										2.58		2.58
195												2.58

Action time at -65° F, 2.77 msec (unheated cartridges).

TABLE VIII. Velocities Obtained Under Various High Temperature-Time Exposures (WC 870 AL 42678 Propellant-M52A3B1 Primer)

Exposure Temp (° F)	Velocity (fps) after Exposure Time (hr) of											
	1	2	3	4	5	6	7	8	9	10	11	12
Firing Temperature: 70° F												
235												
230	3402	3398										
225	3396	3398										
220		3380	3404									
215			3416	3390								
210				3384		3390		3415				
205								3399	3417			
200										3424		3409
195												3371

Velocity at 70° F, 3357 fps (unheated cartridges).

Exposure Temp (° F)	1	2	3	4	5	6	7	8	9	10	11	12
Firing Temperature: -65° F												
235												
230	3257	3256										
225	3259	3247										
220		3248	3242									
215			3246	3255								
210				3220		3253		3257				
205								3237	3256			
200										3259		3235
195												3266

Velocity at -65° F, 3218 fps (unheated cartridges).

None of the exposure conditions resulted in pressures exceeding 70,000 psi when the ammunition was fired at -65° F. However, it is not realistic to stipulate that ammunition having a previous history of high temperature exposure should only be fired at -65° F. It follows that the safe operating limit would have to be defined by the 70° F performance, and not that at -65° F.

Action Time - All values were well below the specified safe operating limit of 4.0 msec. In general, increases in both exposure temperature and time resulted in a decrease in action time. Since velocity was relatively insensitive to changes in heating conditions, the decrease in action time with increased severity of exposure condition is probably related to a corresponding decrease in propellant ignition time.

Velocity - While substantial pressure increases were induced by the high temperature exposures, the increase in velocity was relatively small, with all velocities falling in the desired range of 3380 ± 200 fps. The insensitivity of velocity to pressure change is probably related to a decrease in burning progressivity caused by the exposure conditions.

In summary, under certain exposure conditions, pressures in excess of 70,000 psi were obtained when the previously heated ammunition was fired at 70° F. Action times were all less than the specified maximum of 4.0 msec and velocities were all within the desired range of 3380 ± 200 fps.

Low temperature firings of previously heated cartridges did not yield any anomalous results. The differences in pressure, velocity, and action time obtained with the heated cartridges, when fired at 70° and -65° F, were similar to those obtained with unheated ammunition.

The results obtained with ammunition assembled with WC 870 AL 42446 propellant and the M52A3B1 primer are presented in Tables IX, X, XI, and XII.

Following are some comments regarding the results.

Pressure - For the ammunition fired at 70° F, the exposure temperature-time conditions which yielded pressure below the safe operating limit of 70,000 psi are located below and to the left

TABLE IX. Effect of Exposure at Elevated Temperature and Firing at 70° or -65° F (WC 870 AL 42446 Propellant-M52A3B1 Primer)

Firing Temperature: 70° F					Firing Temperature: -65° F				
Exposure					Exposure				
Temp (° F)	Time (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)	Temp (° F)	Time (hr)	Pressure (psi)	Velocity at 78 ft (fps)	Action Time (msec)
70		47,000	3384	2.54	-65		42,800	3234	2.76
	EV	2,700	32	0.01		EV	6,700	35	0.07
	SD	1,100	11	0.01		SD	3,000	14	0.02
200	12	65,000	3425	2.36	200	12	65,000	3329	2.48
	EV	4,100	18	0.05		EV	8,000	36	0.03
	SD	1,400	6	0.02		SD	2,800	15	0.01
205	12	71,300	3442	2.34	205	12	66,200	3336	2.45
	EV	1,500	10	0.03		EV	1,700	8	0.02
	SD	500	3	0.01		SD	600	3	0.01
205	10	70,500	3446	2.37	205	10	68,100	3350	2.45
	EV	2,800	30	0.09		EV	3,300	30	0.07
	SD	1,300	10	0.03		SD	1,100	10	0.02
205	9	64,200	3429	2.41	205	9	64,700	3329	2.53
	EV	3,200	11	0.03		EV	5,100	27	0.04
	SD	1,100	4	0.01		SD	2,100	12	0.02
205	8	65,000	3437	2.38	205	8	65,700	3351	2.49
	EV	2,900	21	0.04		EV	5,200	38	0.02
	SD	1,000	7	0.01		SD	2,000	14	0.01
210	8	70,700	3443	2.35	210	8	67,200	3365	2.43
	EV	1,800	10	0.03		EV	3,600	19	0.04
	SD	800	3	0.01		SD	1,200	7	0.02
210	7	64,800	3426	2.42	210	7	64,200	3320	2.54
	EV	4,800	22	0.08		EV	5,000	29	0.04
	SD	1,800	8	0.03		SD	1,700	11	0.01
215	7	71,200	3440	2.36	215	7	69,300	3337	2.52
	EV	2,500	15	0.09		EV	5,300	45	0.02
	SD	800	7	0.03		SD	1,900	15	0.01
215	6	69,200	3431	2.36	215	6	67,700	3335	2.46
	EV	800	13	0.02		EV	2,600	43	0.06
	SD	300	5	0.01		SD	1,000	15	0.02
220	6	73,000	3452	2.37	220	6	72,500	3385	2.43
	EV	2,300	20	0.03		EV	1,300	10	0.08
	SD	1,000	7	0.01		SD	400	4	0.03
220	5	71,000	3450	2.38	220	5	68,500	3335	2.50
	EV	5,600	27	0.05		EV	3,200	24	0.07
	SD	1,900	10	0.02		SD	1,400	9	0.03
220	4	67,500	3434	2.36	220	4	63,500	3329	2.48
	EV	3,000	21	0.06		EV	2,800	14	0.04
	SD	1,300	8	0.02		SD	1,000	5	0.02
225	4	68,300	3426	2.40	225	4	68,100	3340	2.51
	EV	2,400	15	0.04		EV	3,700	22	0.08
	SD	800	7	0.01		SD	1,300	8	0.03
230	4	73,700	3448	2.39	230	4	74,800	3391	2.46
	EV	2,700	16	0.09		EV	2,200	37	0.12
	SD	900	6	0.03		SD	800	16	0.04
230	3	72,800	3453	2.37	230	3	72,600	3371	2.49
	EV	2,100	13	0.06		EV	4,900	31	0.12
	SD	800	5	0.02		SD	2,000	12	0.04
230	2	65,800	3438	2.41	230	2	65,300	3324	2.58
	EV	2,300	9	0.05		EV	5,700	39	0.07
	SD	1,000	3	0.02		SD	2,000	16	0.02
235	3	73,400	3452	2.37	235	3	76,700	3412	2.47
	EV	4,100	21	0.03		EV	4,400	33	0.15
	SD	1,400	7	0.01		SD	1,800	12	0.05
235	2	68,200	3443	2.41	235	2	67,000	3333	2.52
	EV	3,200	12	0.03		EV	8,100	55	0.04
	SD	1,100	4	0.01		SD	2,600	18	0.02
240	2	75,700	3461	2.37	240	2	74,300	3395	2.45
	EV	1,700	12	0.03		EV	8,000	21	0.04
	SD	600	4	0.01		SD	2,900	7	0.01
240	1	65,000	3434	2.42	240	1	65,300	3327	2.55
	EV	2,400	9	0.07		EV	7,200	29	0.11
	SD	900	3	0.03		SD	2,300	10	0.04
245	1	67,900	3452	2.39	245	1	68,000	3336	2.51
	EV	3,300	21	0.04		EV	3,200	36	0.13
	SD	1,200	7	0.02		SD	1,200	13	0.05
250	1	64,700	3428	2.43	250	1	64,700	3319	2.58
	EV	3,300	18	0.09		EV	6,600	68	0.11
	SD	1,300	6	0.03		SD	2,400	23	0.04
255	1	67,700	3444	2.40	255	1	71,900	3384	2.50
	EV	2,800	11	0.02		EV	8,200	49	0.06
	SD	1,300	4	0.01		SD	2,600	16	0.02

Ballistic results represent averages of five firings.

TABLE X. Pressures Obtained Under Various High Temperature-Time Exposures (WC 870 AL 42446 Propellant- M52A3B1 Primer)

Firing Temperature: 70° F

Exposure Temp (° F)	Pressure (psi) after Exposure Time (hr) of 1	2	3	4	5	6	7	8	9	10	11	12
260												
255	67,700											
250	64,700											
245	67,900											
240	65,000	75,700										
235		68,200	73,400									
230		65,800	72,800	73,700								
225				68,300								
220				67,500	71,000	73,000						
215						69,200	71,200					
210							64,800	70,700				
205								65,000	64,200	70,500		71,300
200												65,000

Pressure at 70° F, 47,000 psi (unheated cartridges).
Temperature-Time conditions below and to the left of the line represent exposures where pressures are equal to or below the **safe operating limit.**

Firing Temperature: -65° F

Exposure Temp (° F)	1	2	3	4	5	6	7	8	9	10	11	12
260												
255	71,900											
250	64,700											
245	68,000											
240	65,300	74,300										
235		67,000	76,700									
230		65,300	72,600	74,800								
225				68,100								
220				63,500	68,500	72,500						
215						67,700	69,300					
210							64,200	67,200				
205								65,700	64,700	68,100		66,200
200												65,000

Pressure at -65° F, 42,800 psi (unheated cartridges).

TABLE XI. Action Times Obtained under Various High Temperature-Time Exposures (WC 870 AL 42446 Propellant-M52A3B1 Primer)

Exposure Temp (° F)	Action Time (msec) after Exposure Time (hr) of											
	1	2	3	4	5	6	7	8	9	10	11	12
						Firing Temperature: 70° F						
260												
255	2.40											
250	2.43											
245	2.39											
240	2.42	2.37										
235		2.41	2.37									
230		2.41	2.37	2.39								
225				2.40								
220				2.36	2.38	2.37						
215						2.36	2.36					
210							2.42	2.35				
205								2.38	2.41	2.37		2.34
200												2.36

Action Time at 70° F, 2.54 msec (unheated cartridges).

Exposure Temp (° F)	1	2	3	4	5	6	7	8	9	10	11	12
						Firing Temperature: -65° F						
260												
255	2.50											
250	2.58											
245	2.51											
240	2.55	2.45										
235		2.52	2.47									
230		2.58	2.49	2.46								
225				2.51								
220				2.48	2.50	2.43						
215						2.46	2.52					
210							2.54	2.43				
205								2.49	2.53	2.45		2.45
200												2.48

Action Time at -65° F, 2.76 msec (unheated cartridges).

TABLE XII. Velocities Obtained under Various High Temperature-Time Exposures (WC870 AL 42446 Propellants-M52A3B1 Primer)

Exposure Temp (° F)	Velocity (fps) after Exposure Time (hr) of 1	2	3	4	5	6	7	8	9	10	11	12
						Firing Temperature: 70° F						
260												
255	3444											
250	3428											
245	3452											
240	3434	3461										
235		3443	3452									
230		3438	3453	3448								
225				3426								
220				3434	3450	3452						
215						3431	3440					
210							3426	3443				
205								3437	3429	3446		3442
200												3425

Velocity at 70° F, 3384 fps (unheated cartridges).

Exposure Temp (° F)	1	2	3	4	5	6	7	8	9	10	11	12
						Firing Temperature: -65° F						
260												
255	3384											
250	3319											
245	3336											
240	3327	3395										
235		3333	3412									
230		3324	3371	3391								
225				3340								
220				3329	3335	3385						
215						3335	3337					
210							3320	3365				
205								3351	3329	3350		3336
200												3329

Velocity at -65° F, 3234 fps (unheated cartridges).

of the line in Table X. Ammunition exposed to conditions located above the line yielded pressures above 70,000 psi. A partial profile is similarly indicated for the -65° F firings. At the higher exposure temperatures, the profiles defining the safe operating conditions for both firing temperatures are, in general, similar. While the ammunition can withstand 12 hours (which is believed to represent a realistic maximum period for which ammunition would be subjected to extreme temperatures) at 200° F without exceeding the pressure limit, the exposure has a serious effect upon the ballistic performance. It is seen that the heated ammunition yielded a pressure (at 70° F), 18,000 psi greater than that obtained with the unheated cartridge. As shown in Figure 1, while the safe operating limit profiles for ammunition assembled with AL 42446 and AL 42678 propellants are, in general, similar, the former exhibited slightly superior temperature resistance (i.e., higher safe operating conditions). The slight superiority was probably attributable to minor differences in ballistic stability of the two propellant lots, as well as the fact that standard ammunition loaded with AL 42446 yielded lower pressures than that with AL 42678 - 47,000 psi and 50,100 psi, respectively. A greater pressure increase could therefore be tolerated with the former before the 70,000 psi maximum was reached. Thus, it is desirable that the required velocity be attained at as low a chamber pressure as possible.

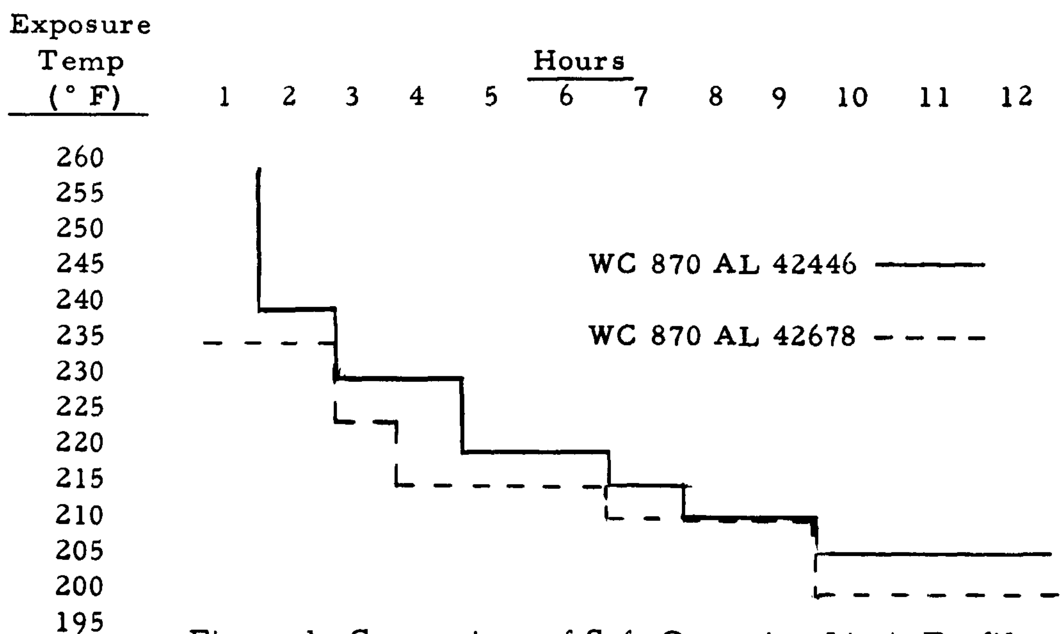


Figure 1. Comparison of Safe Operating Limit Profiles

A significant difference between AL 42678 and AL 42446 propellant in regard to the effect of temperature upon performance was noted. With the former, the differences in pressure obtained with heated cartridges fired at 70° and -65° F were similar to those obtained with the unheated ammunition. For identical heating conditions, the pressure at 70° F was approximately 9000 psi greater than at -65° F. The smallest difference obtained in all firings was 5300 psi. However, with the AL 42446 propellant, the differences in pressure (between 70° and -65° F firing temperatures) were considerably smaller. In fact, at the higher exposure temperatures (230° F and above), a considerable number of cases were encountered in which the pressure obtained at -65° F was higher than at 70° F. This anomalous behavior suggested that, among other effects, substantial agglomeration of the AL 42446 propellant occurred at these high temperatures. Subsequent conditioning at -65° F of cartridges containing the agglomerated propellant should cause the charges to be more brittle than those conditioned at 70° F. Increased embrittlement of the agglomerated charge should result in more rapid fragmentation under primer impact. This might serve to overcome the normal effect of temperature upon performance resulting in a faster mass burning rate at the lower temperature. Increasing agglomeration at 240° F and higher would also account for the relatively constant pressure obtained in the 70° F firings with those cartridges heated at 240°, 245°, 250°, and 255° F for one hour. An increase in degree of agglomeration would retard the normal increase in mass burning rate induced by higher exposure temperatures.

Action Time - All values were well below the specified safe operating limit of 4.0 msec. The maximum individual action time obtained in all firings of heated cartridges assembled with the AL 42446 propellant was 2.64 msec (heated at 250° F for one hour and fired at -65° F). In general, for a given temperature, an increase in length of exposure resulted in a decreased action time. Since velocity was relatively insensitive to changes in exposure time at a given exposure temperature, the decrease in action time is probably related to a corresponding decrease in propellant ignition time.

Velocity - While substantial pressure increases were induced by the high temperature exposures, the increase in velocity was small with all velocities falling in the desired range of 3380 ± 200 fps. The relative insensitivity of velocity to pressure change is probably related to a decrease in burning progressivity induced by the high temperature-time exposure conditions.

In summary, as with firings of ammunition containing WC 870 AL 42678 propellant, certain temperature-time conditions caused pressures in excess of 70,000 psi when the ammunition was fired at 70° F. However, unlike the AL 42678 propellant, pressures above 70,000 psi were also obtained in some of the -65° F tests. Action times were all less than the specified maximum of 4.0 msec and velocities were all within the desired range of 3380 ± 200 fps.

Effect of High Temperature Upon Propellant Properties

As shown above, ammunition subjected to severe high temperature-time exposures yielded pressures exceeding the safe operating limit of 70,000 psi when fired at 70° or -65° F. These high pressures, which are irreversible changes in ballistic performance, are approximately 40 percent greater than the pressures obtained with standard unheated ammunition. Previous investigations have shown the propellant to be the primary cause of chamber pressure increases obtained under accelerated storage conditions at temperatures ranging up to 150° F. Studies were therefore conducted to determine whether the increases observed in this program were attributable to chemical (e.g., loss of deterrent or volatiles) or physical (e.g., migration of the deterrent coating deeper into the grain) changes in the propellant.

Standard cartridges loaded with WC 870 AL 42446 propellant were heated under three exposure conditions similar to those used in the ballistic evaluation phase of this program. These were 200° F-12 hours, 225°F-6 hours, and 250° F-1 hour. The cartridges were then disassembled and chemical and microscopic studies of the propellant were conducted.

Chemical Analysis

Analyses were conducted to determine whether the above exposure conditions induced chemical changes in the propellant which correlated with the large pressure increases obtained with heated ammunition. For comparison, a similar analysis of the unheated propellant was conducted. The results are presented in Table XIII.

TABLE XIII. Chemical Analysis of WC 870 AL 42446 Propellant Subjected to Various Exposure Conditions

	Chemical Analysis (%) after Exposure Condition of			
	Unheated	200°F-12 hr	225°F-6 hr	250°F-1 hr
Nitroglycerin	9.36	9.36	9.31	9.30
Dibutylphthalate	6.57	6.31	6.22	6.43
Moisture & volatiles	0.88	1.02	1.05	1.10
Dinitrotoluene	0.60	0.45	0.45	0.39
Diphenylamine	0.69	0.35	0.11	0.54
Total stabilizer*	1.04	0.93	0.67	1.05

*As diphenylamine

The slight differences between the chemical analyses of the unheated propellant and those subjected to the high temperature exposure conditions cannot account for the high pressures obtained with the latter. (Cartridges subjected to exposure conditions similar to the above yielded pressures in the range 65,000 to 70,000 psi, while the standard cartridge yielded a pressure of 47,000 psi.)

Microscopic Examination

Microscopic studies were conducted to investigate deterrent migration in the propellant grains as induced by the high temperature exposure. Like most propellants used in small arms, the deterrent (dibutylphthalate) in the WC 870 propellant is applied in such a manner as to penetrate the grain to the depth required to yield the desired burning rate progressivity and velocity-pressure ratio. The depth of penetration is small, relative to the radius of the grain. Migration of the deterrent further into the grain (as might be caused by high temperature exposure) would reduce the deterrent concentration near the surface. This would serve to increase the initial burning rate, causing a corresponding increase in the peak pressure and a less efficient ballistic cycle.

Samples of the propellants exposed to the different heating conditions were frozen in gelatin and sections of 0.004 in. thickness were prepared with a Spencer sliding microtome. These sections were mounted on glass slides and examined through a microscope using both transmitted and reflected light. The line of demarcation between the translucent deterred layer and the undeterred balance of the grain was sharp and narrow in the unheated sample. On the other hand, the division between the deterred and undeterred phases of the heated samples was more diffuse, suggesting further penetration of the deterrent into the grain.

While the above microscopic studies were inconclusive, previous findings have demonstrated that deterrent migration was the primary cause of ballistic instability at temperatures ranging up to 150° F.[2, 4] In view of the absence of changes in the overall chemical composition, it is believed that the increases in pressure obtained with the heated samples in these tests are similarly related to migration of deterrent.

Agglomeration of Propellant

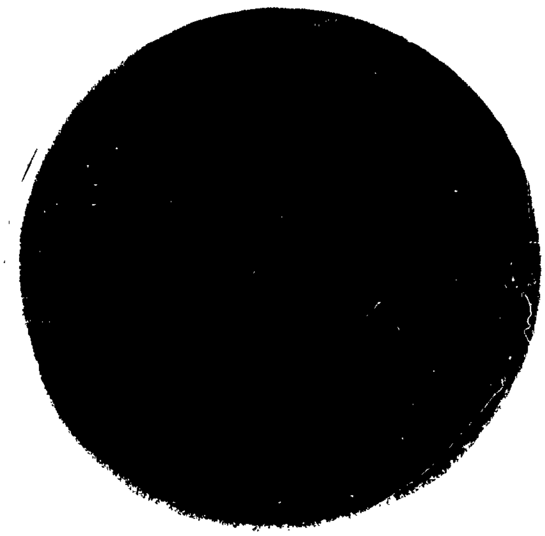
As shown in Tables IX and X, the peak pressures obtained in 70° F firings with WC 870 AL 42446 propellant were relatively insensitive to increases in exposure temperatures above 240° F. (The pressures obtained after one hour exposure at 240°, 245°, 250° and 255° F were all similar.) Since at lower exposure temperatures the peak pressures increased with temperature for a given exposure time, this insensitivity to exposure temperature was anomalous.

Two possible explanations for this behavior were considered. One involved the assumption that the 240° F-1 hour exposure served to drive the deterrent to its maximum possible depth in the grain. Higher exposure temperatures, therefore, would not result in higher pressures since no further deterrent penetration could be attained. However, this explanation is not consistent with the data since the pressure obtained after the 240° F-two hour exposure was 10,700 psi greater than that obtained in the one-hour exposure.

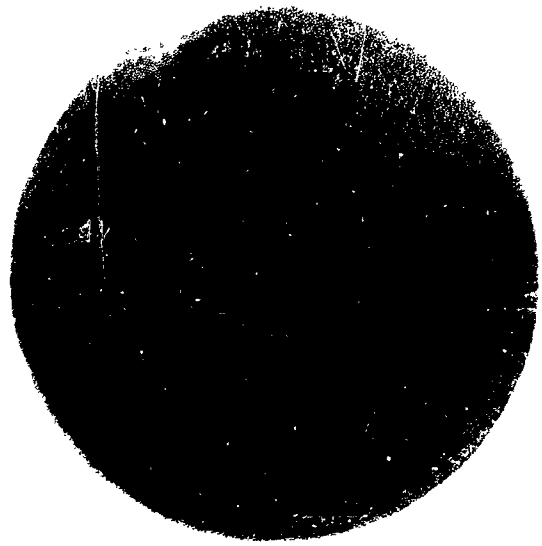
The other explanation involved the assumption that at these extremely high temperatures (240° F and above), considerable agglomeration of the initially free-flowing ball propellant occurred, resulting in less effective ignition and a decreased mass burning rate. If such was the case, then the increase in agglomeration with temperature above 240° F would counteract the pressure increase normally caused by increased exposure temperature.

To determine the degree of agglomeration occurring at high temperatures, cartridges containing WC 870 AL 42446 propellant were heated under the following conditions: 200° F-twelve hours, 225° F-six hours and 250° F-one hour. After cooling, the projectiles were gradually pulled while the round was in a vertical position. The propellant charge was then removed through the neck of the case by gently tapping the cartridge. The case neck is of considerably smaller diameter than the balance of the case. Consequently, even if agglomeration occurred throughout the entire propellant bed, the maximum diameter of the agglomerated piece that could be removed in this manner was that of the case neck. The balance would be obtained as loose propellant.

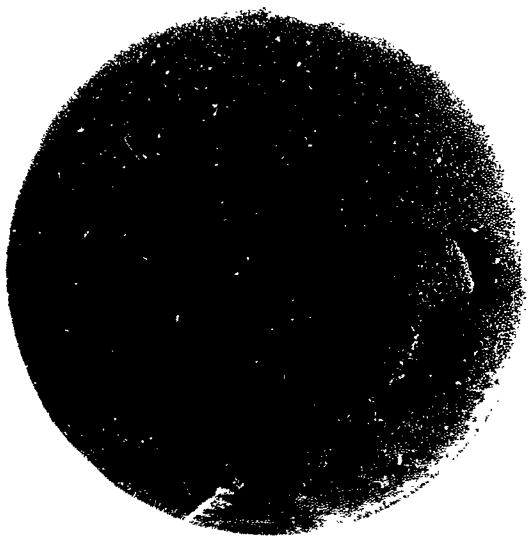
The appearance of the propellant removed in this manner is illustrated in Figure 2. For comparison, the appearance of the propellant before heating (loose, free-flowing propellant grains) is also illustrated. It is seen that the heated propellants all exhibited some degree of agglomeration. The appearance of the 200° F-twelve hours and the 225° F-six hours samples indicated partial agglomeration of the propellant bed, while that of the 250° F-one hour exposure suggested practically complete agglomeration. The diameter of the agglomerated "sticks" of propellant was equal to that of the case neck (the maximum which could be obtained). The agglomerated pieces, however, could be readily separated into loose propellant grains. The high degree of agglomeration obtained at 250° F could affect the ignition and mass burning rate.



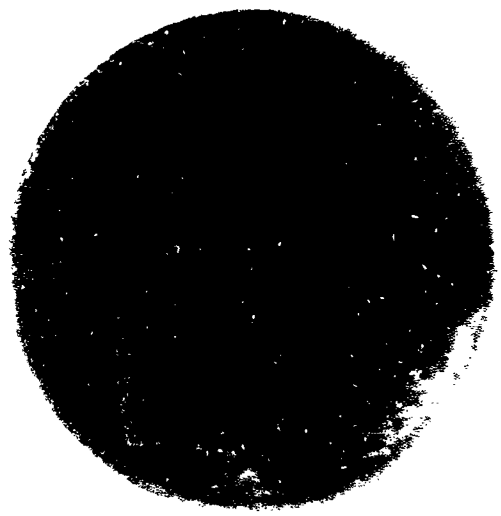
Unheated



200°F - 12 Hours



225°F - 6 Hours



250°F - 1 Hour

Figure 2. WC 870 AL 42446 Propellant Heated under Various Conditions in Cartridge

This concept of agglomeration and its effects may not provide the complete explanation. Investigations regarding the development of molded propellant charges for small arms caseless ammunition[5] have shown that ballistic performance similar to that obtained with loose propellant can be obtained with the same propellant molded to produce a rigid integrated charge having a desired form. (The molded charge could be taken to represent an extreme case of the agglomerated pieces described above). However, the ignition and mass burning rate properties of the molded charge are slightly slower than those of the corresponding loose propellant. Thus, the agglomeration concept provides, at least, a partial explanation for the insensitivity of pressure to increasing exposure temperatures above 240° F.

DISCUSSION

The large temperature coefficient of pressure of standard M55 ammunition (containing WC 870 propellant) was found to be the primary factor limiting high temperature usage of the ammunition. If ammunition is fired above 185° F, there is danger that the 70,000 psi safe operating limit will be exceeded.

For ammunition fired at 70° F or -65° F (after high temperature exposure), higher temperature limits could be tolerated before the 70,000 psi safe operating limit was exceeded. The pressure increase obtained in this phase of the program represents a permanent change induced in the ammunition and is not related to the temperature coefficient of pressure.

In the range 200° to 205° F, pressures in excess of the 70,000 psi safe operating limit were obtained after the maximum exposure period of twelve hours. As the limiting exposure conditions in this phase were a function of temperature and time, higher temperatures could be tolerated, but for shorter periods of time. It is not practical, however, to determine the precise cumulative temperature-time history to which ammunition has been exposed. Since the rate of change of ballistic performance at or above 200° F is relatively rapid, ammunition exposed to temperatures of 200° F or above for several hours duration should be regarded as unfit for use.

If the effect of the large temperature coefficient of pressure were to be superimposed on the permanent changes induced in previously heated ammunition, dangerously high pressures could result. Such a condition might develop if ammunition was carried for several missions involving severe aerodynamic heating of the ammunition boxes and gun compartments and then fired while at elevated temperature.

The deterrent (dibutylphthalate) used in WC 870 propellant is relatively mobile at temperatures of the order of 200° F (which is considerably above the temperature at which the deterrent is applied during the manufacturing process). Consequently, there appears to be little hope of minimizing the permanent pressure increases (ballistic instability) obtained at these temperatures. However, the temperature-time conditions defining the safe operating limit could be improved if the temperature coefficient of pressure, the limiting factor, were reduced (or even made negative at higher temperature). Work directed toward reduction of the temperature coefficient of ballistics resulted in the rolled ball propellant-primer system (X-2048 propellant-FA T27E1 primer) for the 20 mm M55 cartridge which has a substantially smaller temperature coefficient of velocity, pressure, and action time than that obtained with the standard cartridge (WC 870 propellant - M52A3B1 primer).(6) Tests conducted at Aberdeen Proving Ground(7) confirmed this improvement in temperature coefficient of ballistics. In addition, barrel erosion tests revealed considerably greater barrel life than that obtained with the standard cartridge or with any of the other propellant-primer systems under development for 20 mm ammunition.(8)

CONCLUSIONS

1. The large temperature coefficient of pressure of standard M55 ammunition is the factor limiting its high temperature usage. Firings at 185° F yielded chamber pressures above the safe operating limit of 70,000 psi. At this temperature, increased exposure time (to a maximum of twelve hours) had no significant effect upon peak pressure.

2. The limiting exposure conditions for ammunition subjected to exposure at elevated temperature and fired at 70° and -65° F were a function of temperature and time. Ammunition exposed to temperatures in the range of 200° F for twelve hours yielded pressures above 70,000 psi. Similar pressures were obtained with ammunition heated at higher temperatures for shorter periods of time. The data obtained permitted preparation of nomographs defining the exposure temperature-time conditions which result in pressures exceeding the safe operating limit.

3. Exposure at -65° F for twelve hours had no significant effect upon ballistic performance, beyond that normally due to temperature coefficient of ballistics.

4. The high temperature ballistic performance of ammunition assembled with two WC 870 propellant lots was essentially similar.

5. The large pressure increases obtained with ammunition subjected to high temperature-time exposure, and fired at 70° and -65° F, are believed attributable to migration of the deterrent coating of the propellant. The slight changes in chemical composition of WC 870 propellant induced by these exposure conditions could not account for the large pressure increases.

6. Exposure of cartridges containing WC 870 propellant to temperatures above 200° F resulted in significant agglomeration of the propellant.

RECOMMENDATIONS

It is recommended that

1. Standard ammunition subjected to temperatures of the order of 200° F or greater for several hours be regarded as unfit for use.

2. The effect of thermal cycling upon the temperature-time limits for safe operation of standard ammunition be investigated.

3. The temperature-time limits for safe operation of cartridges assembled with rolled ball propellant be determined.

4. The temperature-time limits for safe operation of all cartridges under development be determined.

APPENDIX

PROPELLANT DESCRIPTION SHEET

U. S. Army Lot No. 42446 of 1956 Mfr. Lot No. .... Type .... For 20 mm, Model of M55
WC 870 Lot 1 Type II Class 4 Packed Weight: 20,000 lb.
Manufactured at Olin Mathieson Chemical Corp., E. Alton, Ill.
Contract No. DA-23-072-ORD-982 Date 4-6-56 Specification No. FA PD SP 26C Revision of 22 June 1955

NITROCELLULOSE

Accepted blends (Nos.) Blend of new nitrocellulose & rework material.
Lot number undeterminable.

Nitrogen Content	K. I. Starch Test (65.5° C.)	Stability Test (135° C.)
Maximum	Maximum	Maximum
Minimum	Minimum	Minimum
Average	Average	Average
		Explosion

MANUFACTURE OF POWDER

Total weight of solvent per pound pyro .... Consisting of .... pounds alcohol and .... pounds ether per 100 pound solvent. Percentage of remix to whole ....

Temps., °C. From	Temps., °C. To	Process—Solvent Recovery and Drying	Times Days	Times Hours

TESTS OF FINISHED POWDER

COMPOSITION

Constituent	Formula	Mfr.	Inspr.
Potassium Nitrate		.77	
Sodium Sulfate		.07	Nominal
Calcium Carbonate		.54	
Nitroglycerine		8.82	
Dibutylphthalate		6.59	
Nitrocellulose		80.58	
Dinitrotoluene		.49	
Tin Dioxide		.07	
Diphenylamine		.88	
Total volatiles		1.22	
Moisture & Volatiles		1.13	
Residual Solvent		.64	

STABILITY AND PHYSICAL TESTS

	Mfr.	Inspr.
120° C heat test, S. P.	75.	
Explosion	300+	
Dust & Foreign Material		.01
Web	3all	
No. of grains per pound		
Burning surface per pound (sq. inches)		
Grav. density,	.958	
Specific gravity		
Hygroscopicity		
Compression test		

Grain Dimensions		Die (Inches)	Finished Grain (Inches) Manufacturer	Finished Grain (Inches) Inspector	Mean Variation in Per Cent of Mean Dimension Manufacturer	Mean Variation in Per Cent of Mean Dimension Inspector
Length (L)	Granulation		Opening	% Retained		
Diameter (D)			U.S. 16	.00		
Diameter of perforations (D)			18	.16		
Web	Inner		20	9.62		
Web	Outer		25	47.16		
Web	Average		30	42.13		
Web	Calculated		35	.48		
Difference between inner and outer web			40	.14		
in per cent of web average			Pan	.04		
L:D (Y)						
D:d (X)						

Date packed 3-26-56 Date offered 4-2-56 Date sampled 4-3-56
Date test finished 4-6-56 Date description sheets forwarded 4-9-56
Remarks: This lot meets the chemical and physical requirements of FA PD SP 26C
Type of Packing Box Wooden box with copper liner dated 22 June 1955.
Prod. Manager Inspector of Ordnance U.S. Chemist

 U. S. Chemist. 3—6064

PROPELLANT DESCRIPTION SHEET

U. S. Army Lot No. 42678 of 1957 Mfr. Lot No. .... Type .... For 20 mm, Model of M55
WC 870 Lot 10 Type II Class 3 Packed Weight: 5,700 lb
Manufactured at Olin Mathieson Chemical Corp., E. Alton, Ill.
Contract No. DA 23-072-ORD-1122 Date 4-24-57 Specification No. FA PD SP 26D Revision of 2 July 1956

NITROCELLULOSE

Accepted blends (Nos.) Blend of new nitrocellulose & rework material
Lot numbers undeterminable.

Nitrogen Content		K. I. Starch Test (65.5° C.)		Stability Test (135° C.)	
Maximum		Maximum		Maximum	
Minimum		Minimum		Minimum	
Average		Average		Average	
				Explosion	

MANUFACTURE OF POWDER

Total weight of solvent per pound pyro .... Consisting of .... pounds alcohol and .... pounds ether per 100 pound solvent. Percentage of remix to whole ....

TEMPS., °C. From	TEMPS., °C. To	PROCESS—SOLVENT RECOVERY AND DRYING	TIMES Days	TIMES Hours

TESTS OF FINISHED POWDER

COMPOSITION

Constituent	Formula	Mfr.	Inspr.
Tin Dioxide		.74	
Potassium Nitrate		.90	
Dibutylphthalate		6.76	
Dinitrotoluene		.68	
Calcium Carbonate		.42	
Nitroglycerine		8.83	
Diphenylamine		.81	
Total volatiles		1.16	
Moisture & Volatiles		1.15	
Residual Solvent		.76	
Nitrocellulose		80.69	
Sodium Sulfate		.07	Nominal

STABILITY AND PHYSICAL TESTS

	Mfr.	Inspr.
120° C heat test, S. P.	75	
Explosion	300	
Dust & Foreign Material		.01
Web	Ball	
No. of grains per pound		
Burning surface per pound (sq. inches)		
pounds per cu. ft.	.937	
Specific gravity		
Hygroscopicity		
Compression test		

GRAIN DIMENSIONS		DIE (INCHES)	FINISHED GRAIN (INCHES) Manufacturer	FINISHED GRAIN (INCHES) Inspector	MEAN VARIATION IN PER CENT OF MEAN DIMENSION Manufacturer	MEAN VARIATION IN PER CENT OF MEAN DIMENSION Inspector
Length (L)	Granulation		Opening	% Retained		
Diameter (D)			U.S. 16	.00		
Diameter of perforations (D)			18	.13		
Web: Inner			20	7.93		
Web: Outer			25	42.08		
Web: Average			30	48.38		
Web: Calculated			35	.67		
Difference between inner and outer web			40	.49		
in per cent of web average			Pan	.35		
L:D (Y)			Total	100.03		
D:d (X)						

Date packed 4-15-57 Date offered 4-17-57 Date sampled 4-18-57
Date test finished 4-23-57 Date description sheets forwarded 4-24-57
Remarks: This lot meets the chemical and physical requirements of FA PD SP 26D dated 2 July 1956
Type of Packing Box Wooden Box with copper liner.

Prod. Manager Inspector of Ordnance U.S.Chemist
/s/ L. M. Sheldon /s/ C. E. Beyer R/O

REFERENCES

1. M. E. Levy and C. O. Bateman, "Effect of Temperatures above 165° F on the Ballistics of 20 mm M55 Ammunition," Frankford Arsenal Report R-1474, October 1958.

2. M. E. Levy and C. Murray, "Investigation of the Ballistic and Chemical Stability of 7.62 mm Ammunition Loaded with Ball and IMR Propellant," Frankford Arsenal, Final Report on Industrial Engineering Project, June 1962.

3. Conference involving OOAMA and Frankford Arsenal representatives, Hill Air Force Base, Utah, 20 July 1960.

4. M. E. Levy, "Effect of High Temperature Storage upon the Ballistic Stability of Small Arms Ammunition," Frankford Arsenal Report R-1433, January 1958.

5. J. B. Quinlan, E. F. VanArtsdalen, and M. E. Levy, "Combustible Ammunition for Small Arms. I. Development of a Self-contained Propellant Charge," Frankford Arsenal Report R-1552, May 1960.

6. M. E. Levy, "Reduction of the Temperature Coefficient of Ballistics of 20 mm M55 Ammunition," Frankford Arsenal Report R-1600, August 1961.

7. J. H. Hartung and F. Hines, Jr., "Test of Extruded Single Base Cool Burning Propellant for 20 mm Ammunition," Development and Proof Services, Aberdeen Proving Ground, Firing Record S-46387 (Project FA-I/61/38), 1961.

8. A. Victor Nardi, "Development and Engineering Tests of New Cool Burning Extruded and Rolled Ball Type Propellants for 20 mm Aircraft Ammunition," Frankford Arsenal Report R-1613 (to be published).

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DETERMINATION OF TEMPERATURE-TIME LIMITS FOR SAFE OPERATION OF 20 mm AMMUNITION
by M. E. Levy and E. F. VanArtsdalen

Report R-1659, Nov 62; 37 pp incl tables and illus.
OMS Code 5530.21.60111; AF MIPR 42-600-0-1305-6563

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Ammunition assembled with two WC 870 propellant lots was evaluated in this program. In general, the two lots yielded similar performance. Chemical and physical studies were conducted to determine the effect of high temperatures upon propellant properties.

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